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PNW-315 March 1978

PHYSICAL PROPERTIES OF WOODY FUELS IN THE BLUE MOUNTAINS OF OREGON AND WASHINGTON

usda douglas-fir tussock moth · research & development program

by

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and

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Abstract

Physical properties were determined for some fuels in the surface litter of stands in the Blue Mountains of Oregon and Washington. Average and quadratic mean diameters for both 0- to 1/4-inch and 1/4- to 1-inch fuels were determined in stands of Douglas-fir and grand fir, western larch, lodgepole pine, ponderosa pine, subalpine fir, and Engelmann spruce. Specific gravities were also determined for both size classes of Douglas-fir, grand fir, western larch, and lodgepole pine fuels. The heat content was also determined for 0- to 1/4-inch and 1/4- to 1-inch fuels of Douglas-fir, grand fir, western larch, and lodgepole pine and for composite samples of litter and duff. Diameters of particles of some species were significantly different from values reported for similar fuels in Montana. Use of local diameter measurements to calculate fuel loading from planar intersect sampling reduced bias in predicted loadings 4 to 57 percent. Differences in predicted loading caused by use of local determinations of specific gravity ranged from 2 to 44 percent. The heat contents of Blue Mountain fuels were similar to values reported in other regions of the country.

KEYWORDS: Wood properties (physical), fuels (forest fire), fuel survey, calorific value (wood), specific gravity (wood), Oregon (Blue Mountains), Washington (Blue Mountains).

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INTRODUCTION

Prior to the development of the Rothermel (1972) fire spread model, assessments of wildfire hazards were based largely on qualitative evaluation of fuel complexes. The model provides a means for assessing fire spread and intensity given quantitative data on fuels, topography, and probable weather. As a result, more objective fire behavior predictions and, consequently, better assessments of fire hazard can be made.

Input parameters in the Rothermel (1972) model include the ratio of surface area to volume, particle density, low heat content, and fuel loading and depth. The ratio of surface area to volume is calculated from the average diameter (d_a) for each size class of fuel. Particle density is derived from the specific gravity (s) of the fuel. The low heat of combustion is derived from calorimeter tests in the laboratory. Fuel loading and depth are generally determined from field inventory of the fuel complex being modeled.

Brown (1974) standardized field inventory procedures for quantifying downed woody fuels. These inventories provide estimates of the loading (weight per unit area) and depth of particles making up the fuel complex. By Brown's technique, fuel loading for pieces less than 3 inches in diameter can be determined from the equation:

$$W = \frac{11.64 \times n \times d_q^2 \times s \times a \times c}{N\ell}$$

where

W = fuel loading (tons per acre)
n = number of intercepts
d_q = quadratic mean diameter (inches)
s = specific gravity
a = average secant of nonhorizontal angle
c = slope correction factor
N = number of transects
ℓ = length of transect (feet)

In the equation, only d_q, s, and a depend on species. Therefore, the accuracy of inventory estimates will depend, in part, on the values used for these properties. Brown and Roussopoulos (1974) determined that use of the quadratic mean diameter instead of the average diameter reduced bias as much as 16 percent. They also determined that inclusion of a in the equation reduced bias in predicted loading as much as 39 percent.

The d_q and s values obtained in one region may be questionable for inventories of fuel-producing tree species in a different region because of genetic or site variation. Brown (1974) suggests values for d_q (obtained from Brown and Roussopoulos (1974)) and s which can be used for calculating fuel loading. Although these values were determined in the northern Rocky Mountains, they have been used in eastern Oregon and Washington because local data have been lacking.

An extensive inventory of fuel and appraisal of fire hazard in the Blue Mountains of Oregon and Washington were undertaken as part of the Douglas-fir Tussock Moth Program.[2] As part of this study, samples were taken to determine representative values for d_q and s and to see if significant differences exist between Blue Mountain values and those suggested by Brown (1974). In addition to d_q and s, the high heat of combustion was determined for some common Blue Mountain fuels. The results of the diameter, specific gravity, and heat of combustion determinations are reported. Also, fuel loadings predicted by Brown's (1974) data are compared with loadings from data collected in the Blue Mountains.

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[2] The research reported here was financed in part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

METHODS

Field

The study area is situated in the Blue Mountains of Oregon and Washington. The area on which sampling was done lies between Walla Walla and Pomeroy, Washington, on the north and Tollgate and Troy, Oregon, on the south. Forest cover consists primarily of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), and ponderosa pine (*Pinus ponderosa* Laws.) at elevations of less than about 4,500 feet. Above this elevation, subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry), western larch (*Larix occidentalis* Nutt.) and lodgepole pine (*P. contorta* Dougl.) predominate.

For each species, two or three stands were selected for the inventory of fuel properties. Stands were located several miles apart so that the range of conditions could be sampled. Douglas-fir and grand fir occurred in nearly equal proportions in the stands selected for measurement, and particle diameters were not identified by species. Stands of the other species were essentially pure, and particle diameters were identified by species. Particles were sampled along an engineer's tape laid between two trees in each stand. The diameter of each twig (0- to 1/4-inch) or branch (1/4- to 1-inch) intersected by the edge of the tape was measured at the point of intersection to the nearest one-hundred-twenty-eighth of an inch with a caliper. When all particles along the tape were measured, the tape was moved to a new pair of trees and the procedure repeated until an adequate sample had been obtained. The average secant of nonhorizontal angle was not measured because of the preponderance of horizontally distributed particles.

Separate samples of twig and branch material of Douglas-fir, grand fir, western larch, and lodgepole pine were collected for determinations of specific gravity and heat of combustion. Composite samples of duff (L, F, and H layers) were collected from seven stands and placed in soil moisture cans. The seven samples were combined for determination of an average heat of combustion for duff.

Laboratory

The 0- to 1/4-inch and 1/4- to 1-inch material collected in each of four species constituted eight separate samples. From each of the eight samples, four pieces were randomly selected for a representative subsample. An estimate of the sample's average specific gravity was obtained by separating the sample into four groups corresponding to the subsample by which they appeared to be represented. Average specific gravity for material in each sample was then determined by weighting each subsample's specific gravity by the proportion of weight in the group to total sample weight. The air-dry volume of each subsample was determined by immersing the subsample in a graduated cylinder filled with mercury. The volume determination by mercury displacement is a nonstandard technique developed for conifer needles[3] and modified for twigs and branches.[4] The volume of displaced mercury was read with a cathetometer with an accuracy of about ± 1 percent. Subsamples were ovendried and weighed to $\pm 1.8 \times 10^{-5}$ ounces.

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[3] Bunnell, David L. 1968. Method and technique of deriving specific gravity of conifer needles. Unpublished report on file at USDA For. Serv. Intermt. For. and Range Exp. Stn., North. For. Fire Lab., Missoula, Mont., 7 p.

[4] Tuttle, Kenneth L. 1976. Tussock moth wildfire fuels specific gravity and higher heating value determinations. Unpublished report on file at USDA For. Serv. For. Residues Program, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg., 15 p.

Material from each of the eight twig samples was ground to obtain a particle size suitable for determinations of moisture and heat of combustion. Duff samples were ground and separated according to ASTM (American Society for Testing and Materials 1947) method D-21. Half of each sample by weight was combined, mixed, and tested for moisture content and heat of combustion. Moisture contents and higher heating values were determined in duplicate for the ground samples according to ASTM method D-271, except that moisture contents were determined by drying samples at 212°-219°F for 16 hours.

RESULTS AND DISCUSSION

Particle Diameter

Although the individual diameter measurements within a class are not normally distributed, the Central Limit Theorem is assumed to apply to d_a samples of the size collected. Based on this assumption, a test of equality of sample variances of the two populations was conducted. Where significant differences in variance existed, an approximate *t*-test (Snedecor and Cochran 1967) for unpaired data was used to compare d_a from the two samples. A pooled *t*-test was used where differences were not significant.

The *t*-test revealed that the average diameters of some Blue Mountain species and size classes are significantly different from average diameters of similar species and size classes reported by Brown and Roussopoulos (1974)(table 1). Although differences were found, no consistent patterns emerged. For the Blue Mountain data, average diameters for 0- to 1/4-inch western larch, subalpine fir, and

Table 1--*Comparison of Blue Mountain fuel particle average diameters* (d_a) *and variances with values obtained by Brown and Roussopoulos (1974)*

Species	Diameter class	Blue Mountains			Brown and Roussopoulos[1]			F[2]	*t*[3]
		d_a	n	Standard deviation	d_a	n	Standard deviation		
		- - Inches - -		- - - Inches - - -			- Inches -		
Douglas-fir/ grand fir	0-1/4 1/4-1	0.107 .452	234 101	0.161 .662	0.098 .512	1.052 1,030	0.051 .213	9.96* 8.14*	0.846 -.906
Western larch	0-1/4 1/4-1	.140 .399	262 176	.044 .150	.114 .453	716 967	.051 .185	1.37* 1.52*	7.831** -4.227**
Lodgepole pine	0-1/4 1/4-1	.123 .435	200 100	.052 .179	.134 .547	225 228	.043 .213	1.50* 1.42	-2.359* 4.604**
Ponderosa pine	0-1/4 1/4-1	.179 .473	28 100	.265 .704	.177 .453	206 967	.051 .185	27.00* 14.49*	.040 .283
Subalpine fir	0-1/4 1/4-1	.119 .425	306 109	.051 .166	.098 .512	1,052 1,030	.051 .213	1.00 1.64*	6.175** -5.049**
Engelmann spruce	0-1/4 1/4-1	.127 .491	238 147	.055 .198	.098 .512	1,052 1,030	.051 .213	1.15 1.16	7.760** -1.103

[1] Values from table 1, Brown and Roussopoulos (1974).

[2] F-test of the equality of the two population variances.

[3] *t*-test of the equality of the two population average diameters.

* Significant at the 0.05 level.
** Significant at the 0.01 level.

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Material from each of the eight twig samples was ground to obtain a particle size suitable for determinations of moisture and heat of combustion. Duff samples were ground and separated according to ASTM (American Society for Testing and Materials 1947) method D-21. Half of each sample by weight was combined, mixed, and tested for moisture content and heat of combustion. Moisture contents and higher heating values were determined in duplicate for the ground samples according to ASTM method D-271, except that moisture contents were determined by drying samples at 212°-219°F for 16 hours.

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		d_a	n	Standard deviation	d_a	n	Standard deviation		
	- - -Inches- - -			- - - Inches- - - -			-Inches-		
Douglas-fir/ grand fir	0-1/4	0.107	234	0.054	0.098	1,052	0.051	1.11	2.415*
	1/4-1	.452	101	.163	.512	1,030	.213	1.71**	-3.424**
Western larch	0-1/4	.140	262	.044	.114	716	.051	1.36**	7.831**
	1/4-1	.399	175	.150	.453	967	.185	1.53**	-4.217**
Lodgepole pine	0-1/4	.123	200	.052	.134	225	.043	1.43**	-2.359*
	1/4-1	.435	100	.179	.547	228	.213	1.41	-4.914**
Ponderosa pine	0-1/4	.179	28	.061	.177	206	.051	1.42	.190
	1/4-1	.478	100	.185	.453	967	.185	1.00	1.286
Subalpine fir	0-1/4	.119	306	.051	.098	1,052	.051	1.02	6.340**
	1/4-1	.425	109	.166	.512	1,030	.213	1.64**	-5.049**
Engelmann spruce	0-1/4	.127	238	.055	.098	1,052	.051	1.15	7.806**
	1/4-1	.491	147	.198	.512	1,030	.213	1.16	-1.128

[1] Values from table 1, Brown and Roussopoulos (1974).

[2] F-test of the equality of the two population variances.

[3] *t*-test of the equality of the two population average diameters.

* Significant at the 0.05 level.

** Significant at the 0.01 level.

E R R A T A: Please replace pages 4 and 5 of USDA Forest Service Research Note PNW-315 PHYSICAL PROPERTIES OF WOODY FUELS IN THE BLUE MOUNTAINS OF OREGON AND WASHINGTON, by Kevin C. Ryan & Stewart G. Pickford, with these revised, corrected pages.

Englemann spruce intercepts were greater than Brown and Roussopoulos (1974) had found; but for lodgepole pine they were less. For intercepts greater than one-fourth inch, Brown and Roussopoulos' d_a's generally were greater. There were only three cases in which the variance and/or mean were not significantly different at the .05 level.

The effect of differences in the two diameter distributions on predicted loadings was determined by calculating the quadratic mean diameters for the Blue Mountain data and comparing them to the quadratic mean diameters reported by Brown and Roussopoulos (1974) and Brown (1974). Use of the Blue Mountain dq^2 values instead of those suggested by Brown (1974) would result in calculated fuel loading differences ranging from 4 to 57 percent (table 2). In 6 out of 12 cases, predicted fuel loading would be greater if dq values from Brown were used instead of Blue Mountain data.

Specific Gravity

Specific gravities of Blue Mountain fuels were generally higher than those suggested by Brown (1974). The variation in predicted fuel loadings using s data from Brown versus s data from the Blue Mountains ranged from 2 to 44 percent (table 3).

Published data on specific gravities for small diameter fuels are decidedly lacking. Brown (1974) cited data from two known sources. Data from Beaufait et al. (1975), as cited in Brown (1974), were used for comparison because they included the greatest amount of data in common with this study. In both studies, specific gravity was based on an air-dry volume and an ovendry weight. Volumes for the data reported in Brown (1974) were determined by a

Table 2--*Comparison of Blue Mountain squared quadratic-mean fuel diameters* (d_q^2) *with values suggested by Brown (1974)*

Species	Diameter class	Blue Mountains d_q^2	Brown[1] d_q^2	Difference[2]
	Inches	Square inches		Percent
Douglas-fir/ Grand fir	0-1/4	0.0143	0.0122	17
	1/4-1	.230	.304	-24
Western larch	0-1/4	.0216	.0149	45
	1/4-1	.181	.238	-24
Lodgepole pine	0-1/4	.0178	.0201	-11
	1/4-1	.221	.344	-36
Ponderosa pine	0-1/4	.0356	.0342	4
	1/4-1	.262	.238	10
Subalpine fir	0-1/4	.0167	.0122	37
	1/4-1	.208	.304	-32
Engelmann spruce	0-1/4	.0192	.0122	57
	1/4-1	.280	.304	-8

[1] Values from table 2, Brown (1974).

[2] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}} \times 100.$

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Englemann spruce intercepts were greater than Brown and Roussopoulos (1974) had found; but for lodgepole pine they were less. For intercepts greater than one-fourth inch, Brown and Roussopoulos' d_a's generally were greater. In all but one case where d_a was not significantly different, the variance was significantly different, a further indication that the populations are different.

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	1/4-1	.208	.304	-32
Engelmann spruce	0-1/4	.0192	.0122	57
	1/4-1	.280	.304	-8

[1/] Values from table 2, Brown (1974).

[2/] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}}$ X 100.

Table 3--*Comparison of Blue Mountain fuel specific gravities with values suggested by Brown (1974)*

Species	Diameter class	Specific gravity[1]		Difference[3]
		Blue Mountains	Brown[2]	
	Inches			Percent
Douglas-fir	0-1/4	0.61	0.55	11
	1/4-1	.62	.43	44
Grand fir	0-1/4	.58	--	--
	1/4-1	.50	--	--
Western larch	0-1/4	.54	.46	17
	1/4-1	.54	.55	-2
Lodgepole pine	0-1/4	.56	.49	14
	1/4-1	.56	.41	37

[1] Based on air-dry volume and ovendry weight.

[2] Values from table 4, Brown (1974).

[3] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}} \times 100.$

similar mercury displacement technique.[5] Differences between the data cited in Brown (1974) and those from the Blue Mountains may be due to differences in the size class range of the particles reported by Brown. Also, wood volume decreases below the fiber saturation point. Volumes used to calculate specific gravities may vary between the two data sets because of differences in moisture content. Sample twigs in this study had moisture contents ranging from 7 to 10 percent. Other possible sources of differences may have been resin deposits in and bark content of sample twigs. The bark on the majority of these samples was intact when volume was determined.

Fuel Loading

Because both d_q^2 and s enter into the calculation of fuel loading, the results of this investigation have possible significance for future fuel inventories in the Blue Mountains. When bias occurs in estimated values of both d_q^2 and s, errors in prediction are compounded and can become quite large. The combined effect of applying the most suitable d_q^2 and s values in Brown (1974) to Blue Mountain fuel inventories results in prediction errors as high as 70 percent for 0- to 1.4-inch western larch twigs (table 4). In the case of 1/4- to 1-inch Douglas-fir, the greater d_q^2 and lower s values from Brown (1974) tend to offset each other, thereby reducing the percent error. In 9 out of 14 cases, Brown's (1974) values for d_q^2 and s would predict lower fuel loadings than Blue Mountain values.

Heat of Combustion

Higher heating values (table 5) are similar to those reported by Corder (1973). If a constant heat of condensation of 543 Btu/lb of wood is assumed for the water formed as a product of combustion (Byram 1959), the lower heat of combustion values range from 8,114 Btu/lb for 1/4- to 1-inch grand fir to 8,564 Btu/lb for 0- to 1/4-inch western larch twigs. These values are within 7.2 percent of the 8,000 Btu/lb value

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[5] William R. Beaufait. 1977. Personal conversation. U.S. Dep. Agric., For. Serv., Region 1, Missoula, Mont.

Table 4--*Difference in predicted fuel loading between squared quadratic-mean diameter* (d_q^2) *and specific gravity (s) data from the Blue Mountains and from Brown (1974)*

Species	Blue Mountains				Brown			Percent difference
	Diameter class	d_q^2	s	$d_q^2 \cdot s$	d_q^2 [1]	s [2]	$d_q^2 \cdot s$	$d_q^2 \cdot s$ [3]
	Inches	Square inches			Square inches			
Douglas-fir	0-1/4	0.0143	0.61	0.0087	0.0122	0.55	0.0067	30
	1/4-1	.230	.62	.1426	.304	.43	.1307	9
Grand fir	0-1/4	.0143	.58	.0083	.0122	.55	.0067	24
	1/4-1	.230	.50	.1150	.304	.43	.1307	-12
Western larch	0-1/4	.0216	.54	.0117	.0149	.46	.0069	70
	1/4-1	.181	.54	.0977	.238	.55	.1309	-25
Lodgepole pine	0-1/4	.0178	.56	.0100	.0201	.49	.0098	2
	1/4-1	.221	.56	.1238	.344	.41	.1410	-12
Ponderosa pine	0-1/4	.0356	[2] .41	.0146	.0342	.41	.0140	4
	1/4-1	.262	[2] .51	.1336	.238	.51	.1214	10
Subalpine fir	0-1/4	.0167	[2] .41	.0068	.0122	.41	.0050	36
	1/4-1	.208	[2] .40	.0832	.304	.40	.1216	-32
Engelmann spruce	0-1/4	.0192	[2] .34	.0065	.0122	.34	.0041	59
	1/4-1	.280	[2] .34	.0952	.304	.34	.1034	-8

[1] Values from table 2, Brown (1974).

[2] Values from table 4, Brown (1974).

[3] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}} \times 100.$

Table 5--*Heat of combustion for some Blue Mountain fuels*
(In British thermal units per pound)

Species	Higher heat of combustion		Lower heat of combustion	
	Size class		Size class	
	0 to 1/4 inch	1/4 to 1 inch	0 to 1/4 inch	1/4 to 1 inch
Douglas-fir	8,819	8,727	8,276	8,184
Grand fir	8,738	8,657	8,195	8,114
Western larch	9,117	9,103	8,574	8,560
Lodgepole pine	8,839	8,875	8,296	8,332

used as a standard in the National Fire Danger Rating System fuel models (Deeming and Brown 1975) and in mathematical models of fire behavior (Albini 1976). Western larch appeared to have a higher percentage of bark than the other samples, which probably contributed to the higher energy content. The higher heat of combustion for the composite litter and duff samples was 5,421 Btu per pound. This was low compared with heat content of woody fuels. The higher oxidation state and the presence of inorganic substances in the litter and duff were probable causes for the lower heat content.

CONCLUSIONS

Fuel particles are highly variable in their physical properties, even within size classes and within species. The results indicate that significant differences in predicted fuel loadings can occur, depending on the accuracy of data input into the equation. Inventories of small diameter fuels are of little use by themselves. Of greater importance is the significance of fuel bed properties to potential fire behavior. In most wildland fuel complexes, the characteristic ratio of surface area to volume is greater than 500 feet^{-1} (Albini 1976). This is greater than the ratio of surface area to volume of 0- to 1/4-inch twigs. This fact results from the inclusion of needles and other small nonwoody fuels in fuel models. In fire behavior models, these finer elements are more heavily weighted than twigs.

Fuel inventory by the planar intersect method is a time-consuming process for large areas and can be justified only if the additional time required to obtain local values for d and s results in differences in fire potential. Applying fire behavior models to large areas such as is done in the National Fire Danger Rating System (Deeming et al. 1972) probably does not warrant the additional effort. Local data on fuel properties, however, may be important when fire behavior models are applied to specialized situations such as prescribed burning research. In such instances, other fuel elements such as needles and larger diameter branch wood should also be considered.

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METRIC EQUIVALENTS

English		Metric
5/9(°F-32)	=	°C
1 inch	=	2.540 0 centimeters
1 foot	=	0.304 8 meter
1 ounce	=	28.349 5 grams
1 pound	=	0.453 6 kilogram
1 ton per acre	=	2.241 7 metric tons per hectare
1 Btu per pound	=	2 326 joules per kilogram

GPO 985-573

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range
Experiment Station
P.O. Box 3141
Portland, Oregon 97208

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The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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